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Summer Thunderstorms Over Southern California

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ABSTRACT—Ten-day fire weather records from forestry lookouts in the southern California mountains are used to describe summer thunderstorm activity. The distribution of thunderstorms during a typical season closely resembles rainy-day frequencies for summer precipitation in Arizona, thereby supporting the concept that most southern California summer thunderstorms are caused by a westward extension of the same circulation that brings Arizona its "monsoon" rains.

Thunderstorms are also induced by dissipating eastern North Pacific tropical cyclones that move up the west coast of Mexico. Tropical storm tracks, local National Weather Service reports, and fire weather records are used to show which occurrences of thunderstorms can be credited to this tropical cyclone activity and the attendant influx of upper level moisture.

When the data from the summers of 1947–68 are divided into two 11-yr periods using 1957/58 as the break point, a significant increase in thunderstorms and tropical cyclones affecting southern California is noted during the latter period.

1. INTRODUCTION

Each summer, occasional pulsations of warm, humid air invade southern California from the south. These conditionally unstable air masses usually manifest their presence by the appearance of altocumulus cloud streets advancing from the southeast, followed by cumulonimbus buildups over the coastal mountain ranges. On rare occasions, the tropical air arrives coincident with a "chubasco"—a tropical cyclone off the west coast of Mexico.[1]

Early investigators (Campbell 1906, Carpenter 1913, Blake 1933) described the associated thunderstorms and their effect on the local climate. Blake designated them as "Mexican storms" and noted that two synoptic patterns are associated with them. One pattern consists of air approaching from the south and east and is traditionally called the Sonora storm because it was believed to originate in that Mexican state. The other pattern brings in tropical air from the south and west and is due to a dissipating chubasco that has penetrated far enough northward to affect southern California.

Regardless of the weather pattern, the resulting thunderstorms occur primarily over the mountains in southern California (fig. 1). These mountains form a nearly continuous chain that may be divided into two general ranges: the Transverse Range, which runs to the southeast from Point Conception, and the Peninsular Range beginning at the southern end of the Transverse Range, running parallel to the coast, and continuing down into Mexico. This range forms the rugged backbone of Baja California.

Seaward of these ranges is a lowland area consisting of coastal plains and intermediate valleys. It is this lowland area, comprising less than one-half of the area of southern California, that contains the bulk of its population. Northeast of the Transverse Range, and within its rain shadow, is a broad, high, desert country that merges gradually with the low desert of the Colorado River to the east. The Peninsular Range is devoid of a broad, high desert on its eastern flank; instead it plunges steeply to the low desert floor.

Although the mountains in southern California are sparsely populated, summer thunderstorms occasionally cause loss of life and serious damage to property. Because this is the driest season, lightning-set fires pose the greatest threat; but in recent years, there also have been incidences of human injury due to close lightning strikes, washed-out roads and localized flooding caused by downpours, as well as plane crashes and camper trailer accidents caused by extreme turbulence.

Court (1960) shows an average of 60 lightning-est range and forest fires occurring annually for the 11-yr period 1946–56 in southern California. It must be assumed that these are from summer thunderstorms, as lightning associated with winter frontal systems is not common and the forests are usually moistened by the winter rains. In the higher mountains, direct lightning damage to large trees is fairly common, and cattle are occasionally killed while seeking shelter beneath these trees. Human fatalities from lightening strikes are practically nonexistent; the only one the writer could find occurred in July of 1961.

Although thunderstorms form over and just to the east of the mountain crests, their movements occasionally bring them over the populous coastal regions. When this happens, newspapers carry the accounts of spectacular lightning displays and attendant severe weather. The most damage they usually do, besides putting a few power transformers out of service, is to wet the streets and contribute to traffic accidents.

As is characteristic of convectively induced precipitation, the distribution of summer rainfall in southern

[1] *This definition of chubasco has been used recently by authors describing the climate of southern California.*

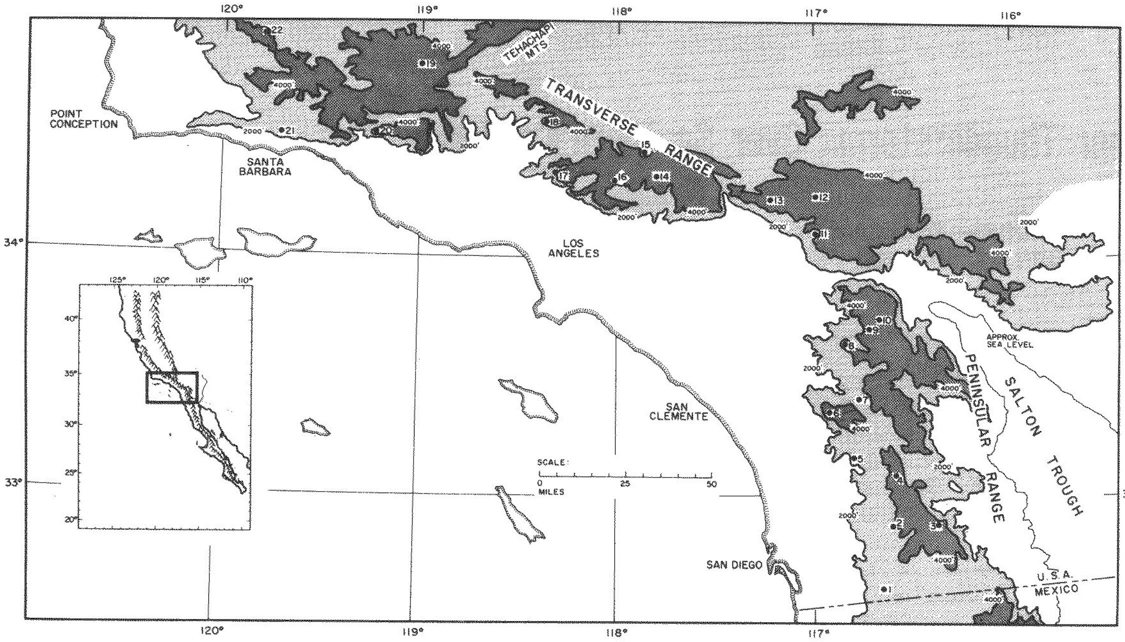

FIGURE 1.—Southern California land form. Contours are drawn for the 2,000- and 4,000-ft levels. Names corresponding to station numbers appear in table 1.

TABLE 1.—*Station descriptions*

Station no.	Station name*	Agency†	Elevation	Precipitation avg. (July-Sept.)	Years with data
			(ft)	(in)	
1	Tecate Peak LO	CDF	3,887	0.4	1947–68
2	Descanso RS	USFS	3,550	0.8	1947–68
3	Laguna Mnt. GS	USFS	6,000	2.4	1957–68
4	Julian FS	CDF	4,220	1.7	1947–68
5	Black Mnt. LO	USFS	4,055	0.6	1947–68
6	Boucher Hill LO	CDF	5,446	0.8	1947–68
7	Oak Grove RS	USFS	2,751	1.0	1947–68
8	Red Mnt. LO	USFS	4,600	1.1	1947–68
9	Keenwild GS	USFS	4,800	2.8	1965–68
10	Tahquitz Pk. LO	USFS	8,828	1.6	1947–68
11	Mill Creek RS	USFS	2,950	0.7	1947–68
12	Butler Peak LO	USFS	8,502	2.0	1958–68
13	Strawberry Pk. LO	USFS	6,150	1.0	1947–68
14	So. Hawkins LO	USFS	7,782	0.5	1947–68
15	Valyermo RS	USFS	3,700	9.7	1947–68
16	Vetter LO	USFS	5,903	0.8	1965–68
17	Mendenhall LO	USFS	4,650	0.3	1964–68
18	Sierra Pelona LO	USFS	4,857	0.4	1965–68
19	Chuchupate RS	USFS	5,250	0.5	1947–68
20	Nordhoff LO	USFS	4,477	0.4	1960–68
21	La Cumbre LO	USFS	3,985	0.2	1957–68
22	McPherson Pk. LO	USFS	5,747	0.9	1958–68

*LO—Lookout, RS—Ranger Station, GS—Guard Station, FS—Fire Station
†CDF—California Division of Forestry, USFS—U.S. Forest Service

California is quite variable in space. It is not uncommon for a reporting station to fail to record even a trace of summer precipitation when deluging rains have occurred only a few miles distant. One of the record rainfall intensities observed in the United States took place at Campo, Calif. (less than 5 mi from station no. 1 in fig. 1), on Aug. 12, 1891, when 11.50 in. of rain fell in 80 min (U.S. Department of Commerce 1960).

2. SOURCES OF DATA

Ten-day fire weather records (WB Form 612–17) are filed by forestry personnel manning fire lookout stations scattered throughout the mountains of southern California. Thunderstorms observed within a 30-mi radius are recorded along with the time the storm began (lightning first seen or thunder first heard) and the time it ended. Comments concerning direction and distance of the thunderstorm from the station, direction of storm movement, number of cloud-to-ground lightning strikes, and resulting fires (if any) are usually included in the reports. Other basic observations include amount and kind of precipitation, temperature (dry bulb and wet bulb), relative humidity, cloud cover, wind speed and direction, as well as indices related to the condition of vegetation when viewed as a fuel source.

Fire lookout stations are occupied at the start of the fire season—usually by June 1 when the forests begin drying after the last of the rainy season storms. The stations remain manned until rainy weather again in the fall diminishes the fire hazard.

Data from 22 stations covering the period from 1947 through 1968 were tabulated and encoded on punched cards. The tabulated facts concerned the occurrence of thunderstorms and/or precipitation (a trace or more), precipitation amount, and the date. The resulting time series of 5-mo seasons (June–October) varied in length because some stations were not manned each year; 13 stations had the full 22 yr of data, five stations had 10 yr, and four had 5 yr.

The 22 stations were picked from a total of approximately 60 occupied each year by U.S. Forest Service and California Division of Forestry personnel in southern California. Selection was based on location and length of record, with those stations having unrestricted visibility and occupying the higher peaks given preference. An attempt was made to pick stations such that the resulting network of observations covered the length of the mountain ranges with not more than 30 mi separating one station from the next (fig. 1 and table 1).

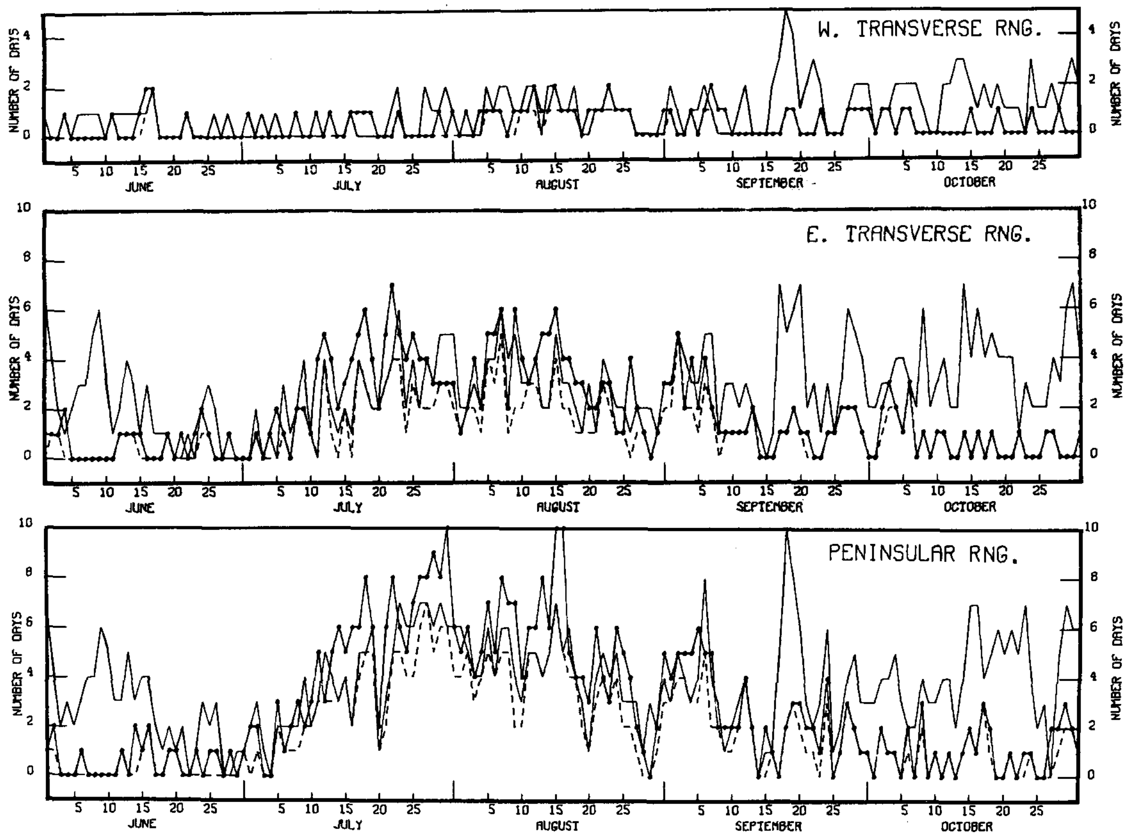

FIGURE 2.—Total number of thunderstorm days (·—·—·), rainy days (——), and days having both thunderstorms and rain (- - -) occurring on each given summer day during the 22 yr from 1947 to 1968.

3. DISCUSSION OF THE THUNDERSTORM TIME SERIES

Because personnel at some stations occasionally miss taking fire weather observations due to fire fighting duties or forestry training classes, it was decided to divide the mountains into three areas and represent each by a single time series that was the combination of all occurrences from each of the stations in that area. This meant that the definition of a "thunderstorm day" for an area would be a day when *at least one* station in that area recorded a thunderstorm, and a "rainy day" as a day when at least one station recorded precipitation. The three mountain areas represented by the thunderstorm data are the Peninsular Range (in the United States) and the eastern and western "halves" of the Transverse Range. The dividing point in the Transverse Range was taken to be at the intersection of the Tehachapi Mountains from the north (fig. 1).

Three time series were generated for each of the mountain areas from the 22 yr of fire season data: a series for the occurrence of thunderstorm days, a series for rainy days, and one for days when both thunderstorms and rain occurred—the reason for the latter series being that many so-called "dry" thunderstorms are observed in which precipitation fails to reach the ground. The combination of occurrences of rain throughout an area hopefully precludes data biasing due to the very localized nature of thunderstorm precipitation and the fact that the thunderstorm need not be in the immediate vicinity to be recorded.

Curves representing the total number of days from the the 22 yr of data when (1) thunderstorms, (2) rain, and (3) both rain and thunderstorms occurred on each summer day are plotted in figure 2 for each of the three areas. Figure 3 shows the yearly distribution by monthly totals of the same three variables.

It is clear that the western Transverse Range is least affected by these summer storms, averaging slightly over two per year for July–September. The eastern Transverse Range, with a yearly average of 11 summer thunderstorms, looks quite similar (in distribution) to the Peninsular Range where the average is 18.

In figure 2, the moderate number of rainy days and low number of thunderstorm days in June illustrate the waning of the winter rainy season; and the sporadic thunderstorms in the last half of the month appear as precursors to the sudden onset of thunderstorm activity in early July. The number of thunderstorm days is highest in July and August with a slight dip during the first few days of August. Despite a gradual decrease in thunderstorm activity in September, there is a peak in the number of rainy days, apparently the result of a combination of (in order of importance) the early appearance of extratropical (winter type) storms, eastern North Pacific tropical cyclone activity, and Sonora rains.

The October curves illustrate the continued decrease in thunderstorms and the approach of cold season rains as the major frontal systems begin to produce precipita-

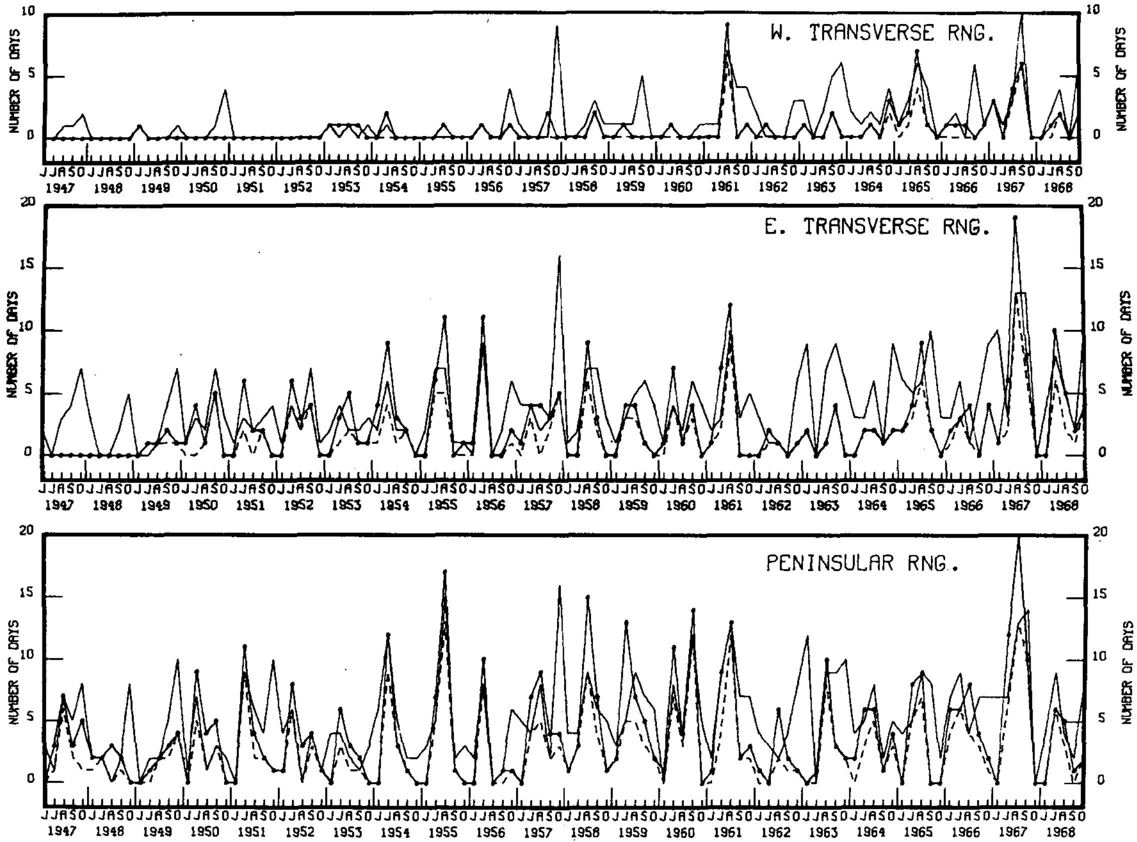

FIGURE 3.—Total number of thunderstorm days (·—·—·), rainy days (——), and days having both thunderstorms and rain (- - -) occurring during each given month for the 22 yr from 1947 to 1968.

tion. It should be noted that these winter fronts are occasionally accompanied by thunderstorm activity.

Summer (July–September) average rainfall amounts, over the periods of available data, for the stations represented in this report are given in table 1. Using 30 yr of data ending in 1958, Coffin (1961) presents a value of 18 percent for the portion of the total annual precipitation that occurs in the months of May through October in the higher mountains of southern California. For the Peninsular Range, Blake's (1933) tabulations credit 8–12 percent of the total annual precipitation for 1928–33 to the Mexican storms.

Figure 4 shows yearly totals of thunderstorm days for July–September. They are plotted as departures from 11-yr means for 1947–57 and 1958–68, which, according to Namias (1972), were coherent regimes for numerous meteorological parameters observed over many areas of the Northern Hemisphere. He has described the climatic and oceanic fluctuations for the 1948–69 period, which were highlighted by the abrupt transition in 1957/58 resulting in the establishment of a new "decadel regime." It appears from figure 4 that southern California summer thunderstorms are yet another manifestation of this climatic break.

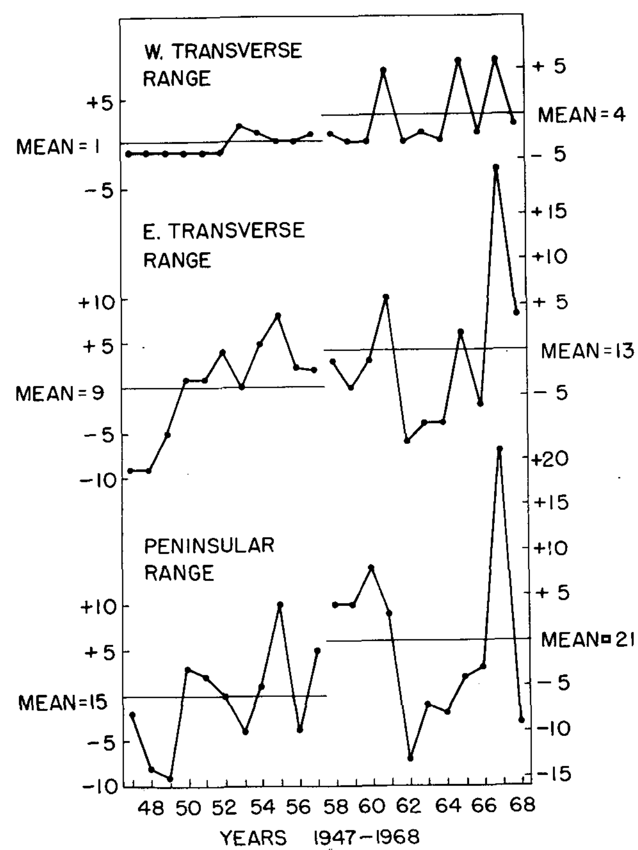

FIGURE 4.—Yearly totals for thunderstorm days for July–September shown as departures from the two 11-yr means for the first and last halves of the 22-yr period.

4. COMPARISON WITH THE ARIZONA SUMMER RAINS

Bryson (1957) has shown, by the use of harmonic analysis on 20 yr of precipitation data for the Southwestern

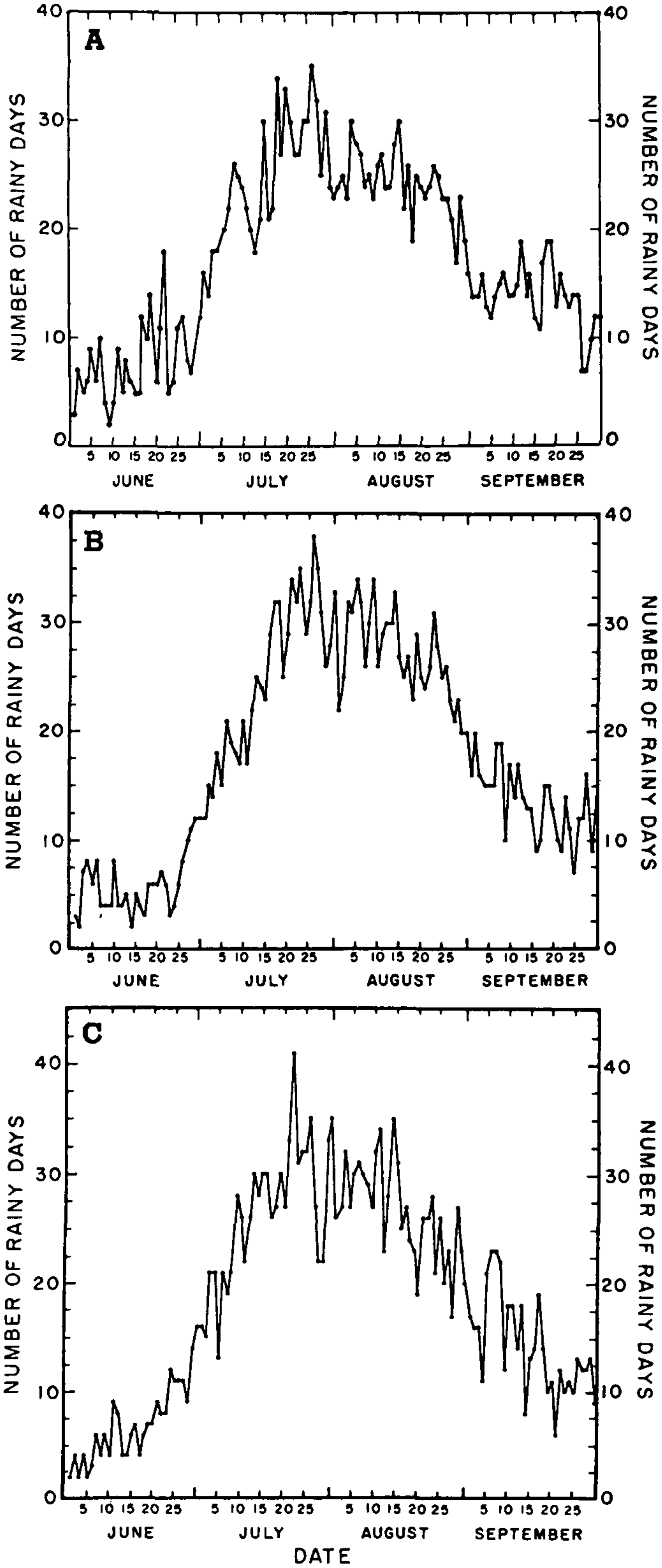

FIGURE 5.—Summer rainy day frequencies for (A) Window Rock (59+ yr), (B) Prescott (62+ yr), and (C) Tucson (67 yr), Ariz. (from Green 1963).

United States and Mexico, that the Arizona summer rains belong to a more widespread precipitation province which he describes as the "Sonoran summer monsoon." Summer rainy-day frequencies from three widely spaced locations in Arizona (Green 1963) are shown in figure 5. The similarity between these curves and corresponding curves for the eastern Transverse and Peninsular Ranges of California in figure 2 is striking.

The sudden onset of summer rains in Arizona has been related to the rapid shift of oceanic (Atlantic and Pacific) subtropical anticyclones to the northwest about the end of June and the subsequent change in air movement aloft at 700 mb over the State from southwesterly to southeasterly flow (Bryson and Lowry 1955). The prominent dip in the number of rainy days during the last week in July or the first week in August is evident not only in each of the stations presented but also in practically all 22 Arizona stations investigated by Green (1963). In July and August, these alternating wet and dry periods correspond, in general, to flow from the southeast and southwest, respectively (Reitan 1957).

The September maximum or singularity in number of rainy days occurring on a particular summer date for southern California is not found in any of the Arizona stations except for Winslow (not shown). This may be due to the longer period of record for the Arizona data, or it may indicate a different synoptic situation for production of September precipitation.

5. HUMID AIR MASS SOURCE REGIONS

The crests of the Transverse and Peninsular Ranges are in all places within 100 mi of the North Pacific Ocean. However, this great and immediate water body does not supply the deep, humid air mass necessary for the development of summer thunderstorms (Willett 1940). In summer, cool upwelled water along the coast plus the presence of the atmospheric inversion over the eastern North Pacific Ocean serve to limit convective activity to a height slightly above the inversion base (Neiburger et al. 1961). The average summer height of the inversion base at the coastline is about 2,000 ft (U.S. Department of Commerce 1965) with an upward slope to the west and to the east. The well-known California stratus, a common feature of the summer weather, is formed below this altitude. California stratus often penetrates to the foothills of the mountain ranges and provides cool weather with a corresponding lack of thunderstorms seaward of about the 2,000-ft contour.

The most recognized source of humid air present in the Western United States during summer is the Gulf of Mexico. In July and August, the upper level warm anticyclone centered over Texas and New Mexico produces southeasterly flow aloft over the southwestern United States (Reed 1933). Wexler and Namias (1938), using isentropic analysis, described the moisture-laden tongue of air associated with the western periphery of the anticyclone. In this way, tropical gulf air is transported northward in a clockwise fashion, the curving moist tongue enhancing precipitation below it.

In a paper dealing with the factors contributing to summer drought in temperate latitudes, Namias (1960) refers to the appreciable variability in geographical position and size of the moist tongue from year to year.

Indeed, a major forecasting problem involves where the moist tongue will enter the United States each summer and how moist it will be. If it swings far west, it can provide Arizona with bountiful monsoon rains and also affect southern California (Byers 1944). About 50 percent of the total annual precipitation in the eastern half of Arizona is attributed to this moist flow from the southeast in summer (Green and Sellers 1964). Southern California, on the other hand, lying well to the west and under the influence of the North Pacific anticyclone, benefits much less from the moist tongue of gulf air.

The closest source to southern California for the production of humid air having the potential for thunderstorm development is the Gulf of California. Summer sea-surface temperatures reach as high as 88°F, and average annual pan evaporation values range between 80 and 100 in. at coastal stations (Roden 1964). For comparison, annual pan evaporation along the Texas gulf coast is 75 in. (U.S. Department of Commerce 1959) with summer sea-surface temperatures in the mid-80s (°F) out in the Gulf of Mexico. However, the limited area of the Gulf of California and the weak air flow from it do not allow it to act as a major source region for southern California. In a paper about the marine influence on the climate of southern California, Coffin (1961) expresses his belief that "the moisture picked up from the Gulf of California is probably only an incidental part of the total water vapor content of the air" that invades southern California from the south each summer. Hales (1972), in describing occasional surges of maritime tropical air northward out of the Gulf of California, places the usual limit of northwestward movement at the lower desert valleys in southern California. The "gulf surge" appears to be stronger in the northeastern direction, and deep (8,000–12,000 ft) surges penetrate far into Arizona, bringing about a sharp increase in thunderstorm activity in that State.

Hastings and Turner (1965), in an analysis of climatological data for Baja California, designate the Gulf of Mexico as the principal source of humid air giving rise to summer thundershowers over the peninsula, but the readily available, low-level moisture source in the Gulf of California must play an important role. Along the eastern flank of the mountains of Baja California, vigorous upslope flow due to intense daytime heating, coupled with a prevailing southeast wind in summer, is available for moving humid Gulf of California air up the steep slopes. If upper level moisture is also present—such as from the Gulf of Mexico—the cells of rising, cooling air can continue to grow into towering cumulonimbus clouds (Namias 1938).

Yet, another humid air mass source is the chubasco—the tropical cyclone off Mexico—which on occasions brings about some of the most active summer weather in southern California.

6. EASTERN NORTH PACIFIC TROPICAL CYCLONES

Equatorward from a line beginning roughly at the southern tip of Baja California and running toward the southwest to about longitude 130°W lies water having sea-surface temperatures that exceed 80°F in summer (U.S. Naval Oceanographic Office 1969). Each year in the months of June through October, tropical cyclones develop in this eastern North Pacific area between 10° and 20°N. Sadler (1964), utilizing satellite observation and ship reports, estimates that, on the average, this area annually produces around 30 tropical cyclones of tropical storm strength or greater, with approximately 12 of these reaching hurricane intensity. The area appears to rank as second only to the western North Pacific in the development of tropical storms and hurricanes (Gray 1968).

The majority of these tropical cyclones take a course between west and northwest and never touch land. The cyclones that move north of west, except for those that recurve into Mexico, soon come under the dissipating influence of cold water (<80°F) and upper level west winds (Sadler 1964).

In September—the month of greatest frequency of cyclones (Rosendal 1962) and the month of highest occurrence of cyclones that recurve into Mexico (Serra C. 1971)—cyclones move more to the north with dissipating systems occasionally entering the United States. Some of these still retain much of their former vigor, especially if they move northward over the Gulf of California with its warm surface water, and may bring torrential rains to the mountains of southern California.

Since tropical cyclones affect the weather hundreds of miles from their centers, rarely a September passes that the weather over southern California is not influenced to some degree by one of these storms. The effects may be only increased relative humidity and higher air temperatures with isolated thundershowers over the mountains; or a general rain may extend over the coastal strip accompanied by some lightning, while inland over the mountains and deserts severe thunderstorms produce heavy rains, hail, and high winds.

A striking illustration of thunderstorm developmen associated with, and hundreds of miles removed from, a tropical cyclone is seen in figure 6. Extensive cumulonimbus clouds developed over the Peninsular Range on Aug. 1, 1970, as the circulation around tropical storm Joyce drew deep, moist air over the mountainous spine of Baja California.

Figure 7 shows eastern Pacific tropical cyclone tracks for the exceptional September of 1939 (Rosendal 1962). In this 1 mo, five cyclones were in position for southern California to feel their effects. The storm that came ashore near Los Angeles on September 25 caused damage in excess of $2 million and took 45 lives. Over 5 in. of rain fell in that city, with more than twice that amount in the mountains.

Tracks of eastern Pacific tropical cyclones, as published annually in the March issue of the *Mariners Weather Log*, were used to determine which occurrences of thunderstorms over southern California from 1947 through 1968 may have been due to a tropical cyclone to the south. Table 2 gives the monthly distribution of cyclones that the author credits with causing thunderstorms. Most of these 34 storms were noted by the San Diego Office of the National Weather Service as causing a flow of tropical

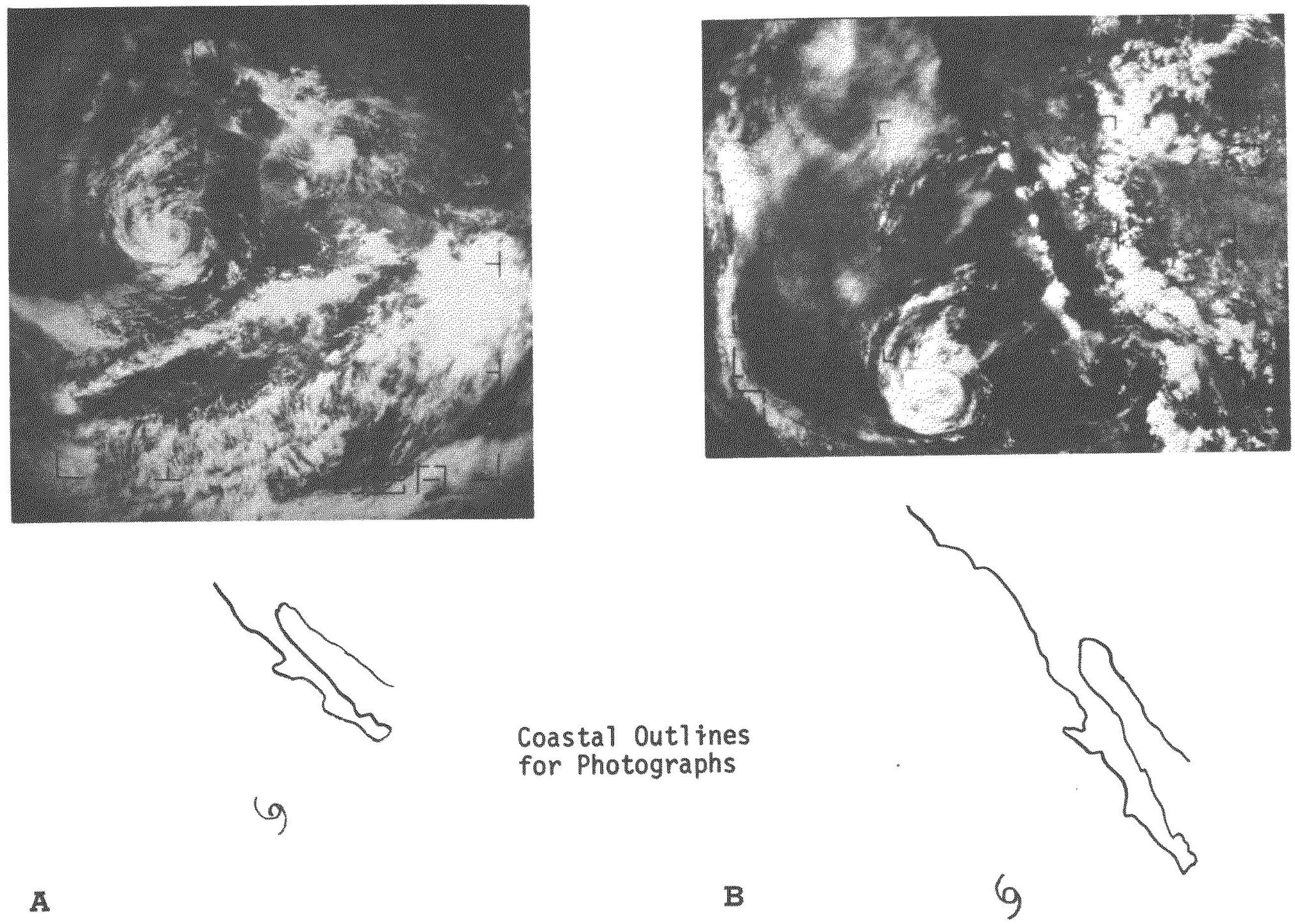

FIGURE 6.—Tropical storm Joyce on Aug. 1, 1970, as viewed by (A) ESSA 8 at 0907 PST and (B) ITOS 1 at 1430 PST (Denney 1971). Note the convective buildups over Baja California.

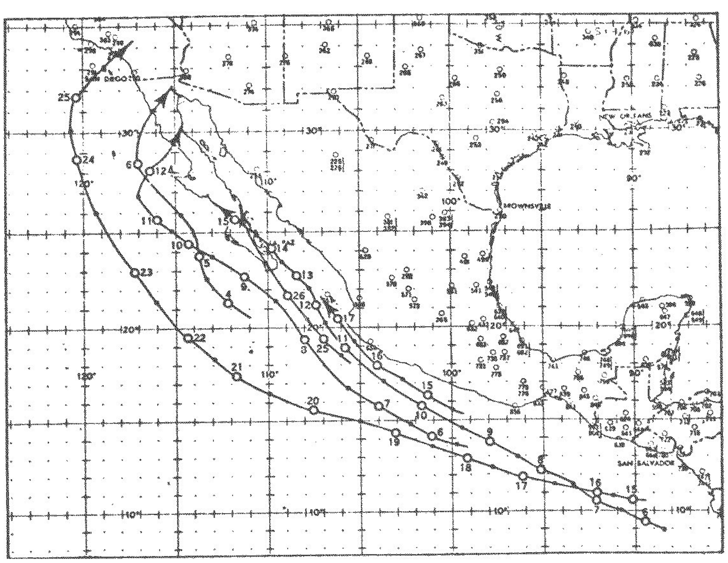

FIGURE 7.—Tracks of tropical cyclones along the west coast of Mexico during September 1939.

Pacific air over southern California at a time when thunderstorms were occurring in the mountains.

For 12 of these cyclones, there was no mention by the local Weather Service Office as to their effects on southern California; but, because of the storms' close proximity to

TABLE 2.—*Monthly distribution of west coast tropical cyclones credited with causing thunderstorms over southern California*

	June	July	August	September	October	Yearly totals
1947						0
1948						0
1949				2		2
1950		1				1
1951						0
1952		1		1		2
1953						0
1954		1				1
1955						0
1956						0
1957			1	1		2
1958		1	1		1	3
1959			1	1		2
1960		1	2	2		5
1961			1	1		2
1962				1		1
1963				1		1
1964			1	1	1	3
1965			1	1		2
1666				2		2
1967		1		1		2
1968		1	1		1	3
Monthly totals	0	7	9	15	3	

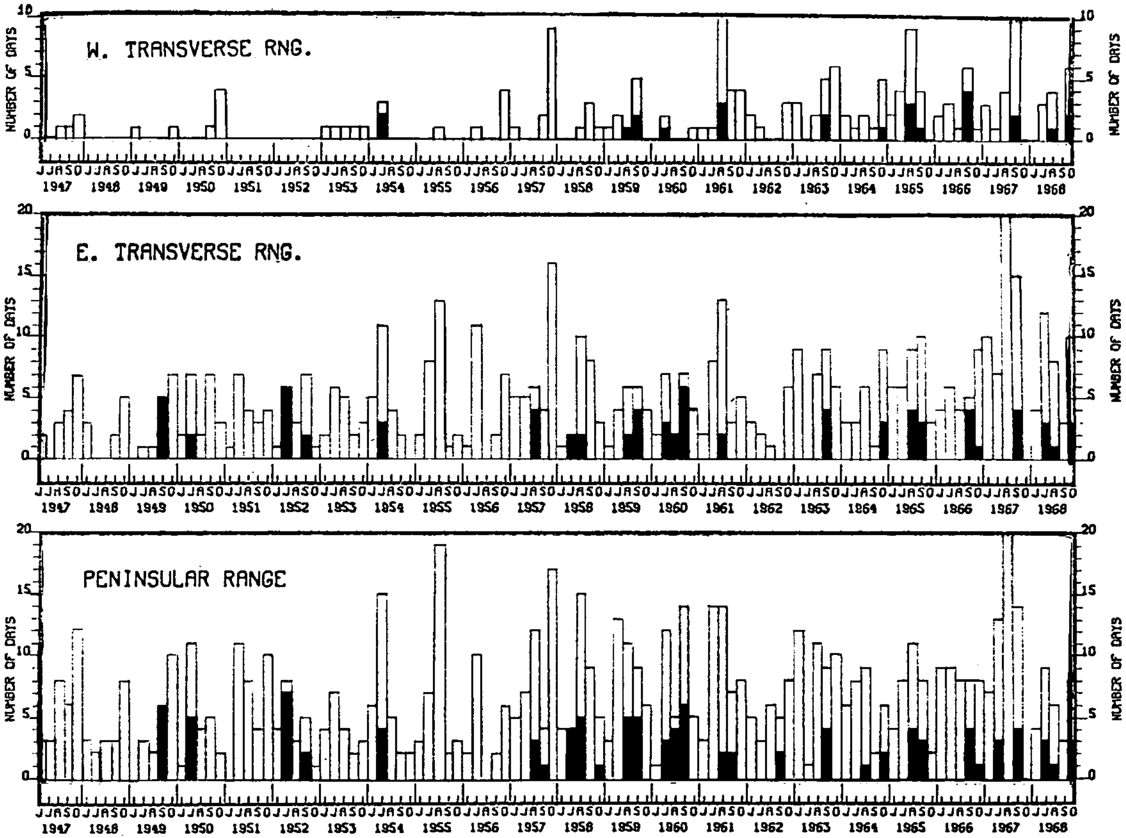

FIGURE 8.—Monthly totals for number of days having rain and/or thunder. Shaded part of bar indicates how many days of the total were attributed to west coast tropical cyclones.

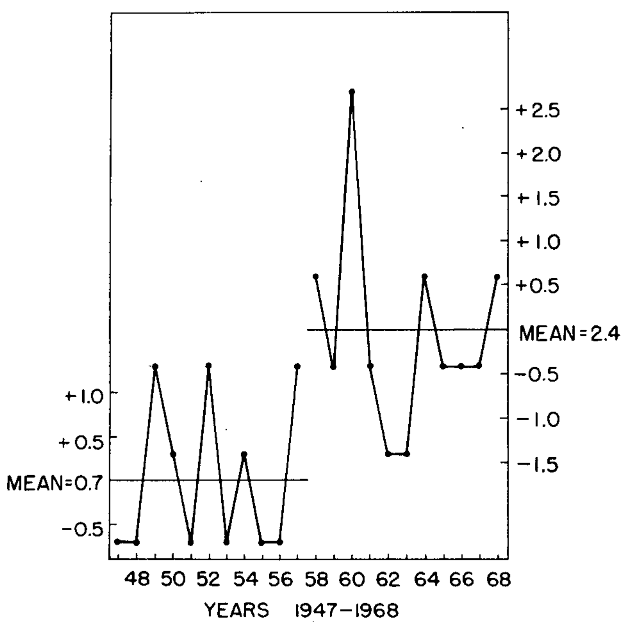

FIGURE 9.—Yearly totals for the number of west coast tropical cyclones credited with causing thunderstorms over southern California. Totals are shown as departures from the two 11-yr means for the first and last halves of the 22-yr period.

San Diego, they were credited with causing the thunderstorms. The circulation around one of these cyclones is often augmented by a southeasterly flow out of the Gulf of Mexico, and at that time it would be difficult to ascribe a southerly flow of moisture over southern California solely to a cyclone to the south.

Figure 8 is a bar graph showing the total number of days each month that rain and/or thunder occurred in the mountain ranges, and the shaded part of the bar indicates how many of these days were credited to tropical cyclone activity. Figure 9 presents yearly totals for the number of tropical cyclones credited with causing thunderstorms over southern California; totals are shown as departures from the 11-yr means for 1947–57 and 1958–68.

While it may be argued that the increase in tropical cyclones affecting southern California during the latter period is possibly due to improved reconnaissance of the tropical eastern North Pacific, it should be pointed out that the tropical cyclones affecting southern California generally follow a track close to the coastline and within the range of detection by coastal stations and vessels traversing the west coast shipping lanes through the Panama Canal.

7. CONCLUSIONS

In southern California, summer thunderstorms occur primarily over the mountains; it is evident from the data that the mountains to the south and east receive many more storms than those ranges to the north and west. Thunderstorm weather begins quite abruptly in early July and tapers off gradually in September; there are alternating periods of high and low thunderstorm activity during the season. The frequency distribution of southern California thunderstorms closely resembles summer rainy-day frequencies for Arizona. This would be expected if the thunderstorms are due to a westward extension of the

Sonoran summer monsoon with its influx of humid air from the Gulf of Mexico. The tropical cyclones that move up the west coast of Mexico are a secondary source for thunderstorm activity. It is evident when comparing 1947–57 and 1958–68 that the incidence of summer thunderstorms in southern California, and possibly tropical cyclones off Mexico which influence California thunderstorms, has increased in the latter period.

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